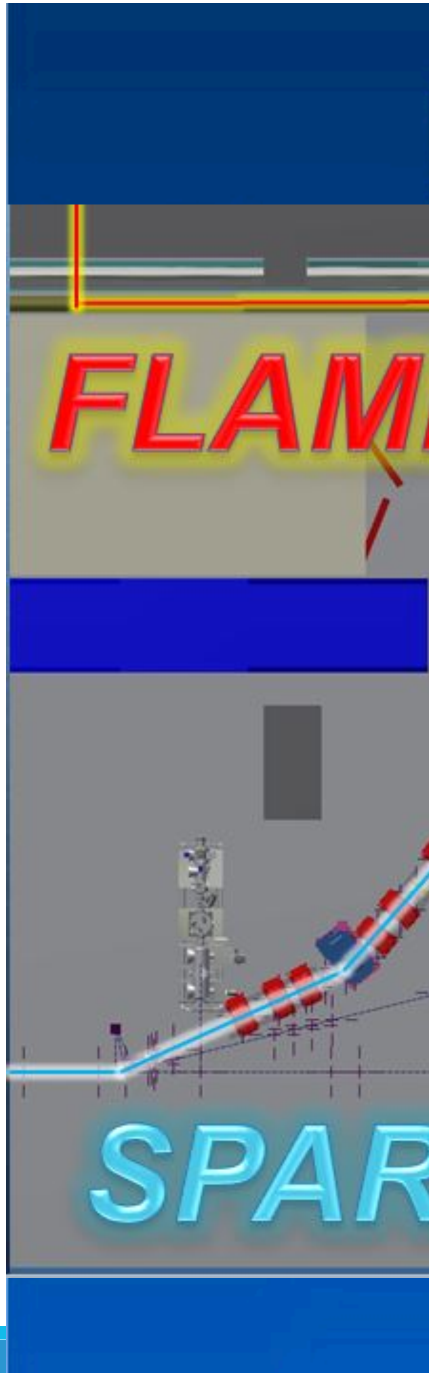
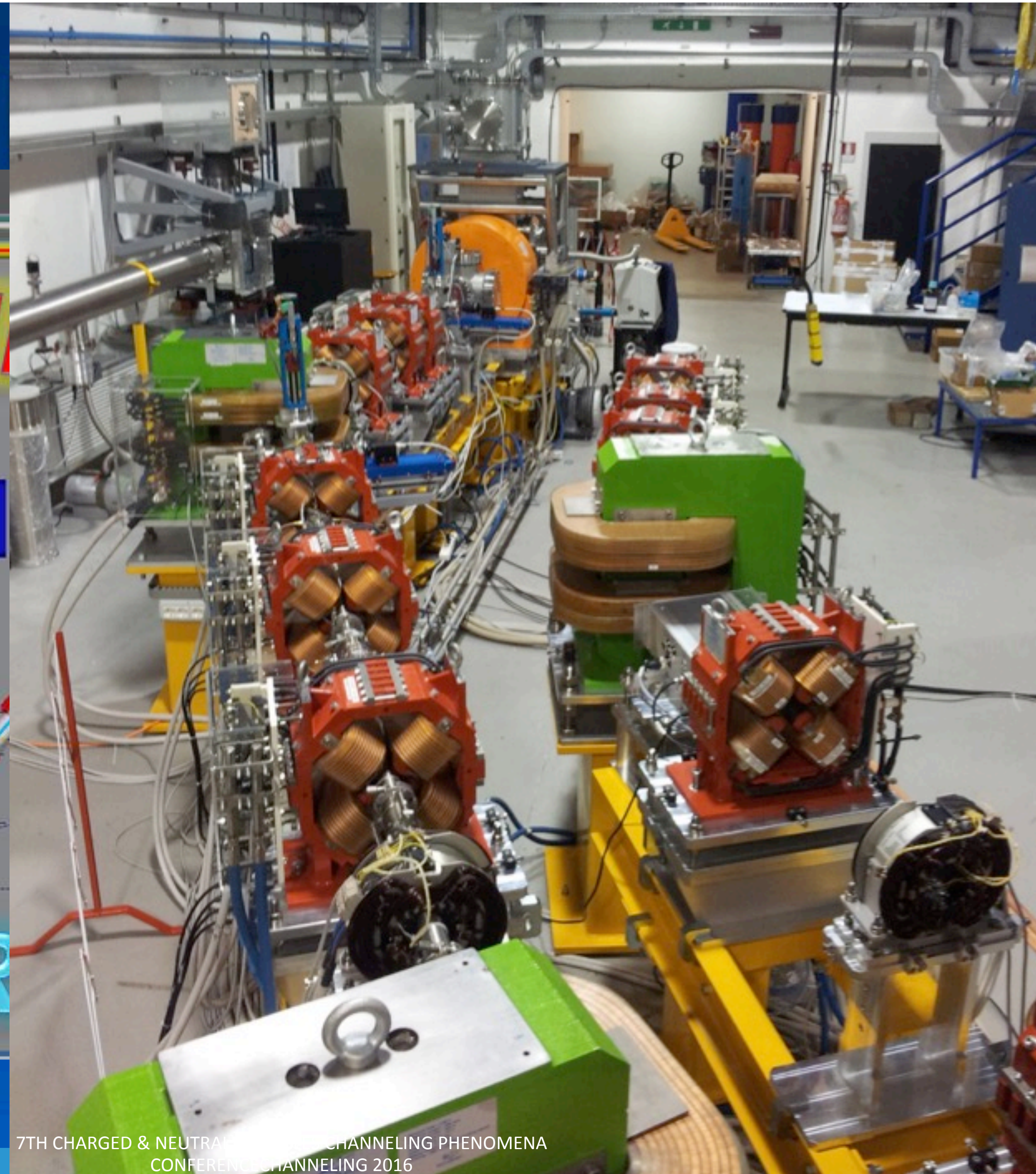
Outline

- The SPARC_LAB Thomson Source: brief description and layout
- 2014-15 results
- The beamline upgrade and new layout
- Simulation results

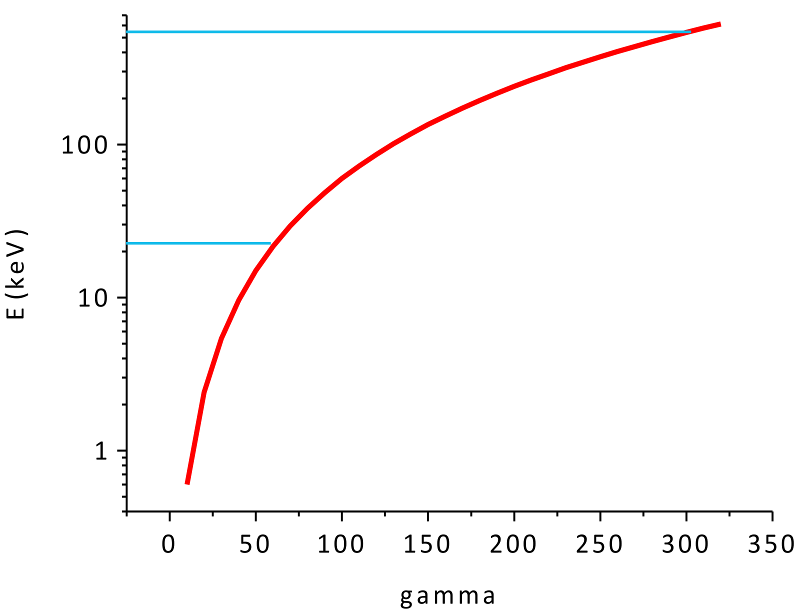
SPARCLAB





SL-Thomson Source Parameters

LASER		ELECTRON BEAM	
Wavelength	800 nm	Bunch charge	0.2-1.0 nC
Compressed pulse energy	1-5 J	Energy	28-150 MeV
Pulse duration/bandwidth	3 -12 (80) ps/nm		
Rep.Rate	10 Hz		
Beam quality M2	<1.5		
Energy stability	10%		
Pointing stability	< 2 µm		
Synchronization with SPARC photoinjector clock			



Applications 20-500 keV

- Mammography
- Identification of fissile materials
- Cristallography
- Microdensitometry 3D for cultural heritage

ELI-γBS test bench for basic machine systems and design

Operating modes:

- **High-flux-moderate-monochromaticity mode(HFM2)** (medical imaging when high-flux sources are needed
- **Moderate-flux- monochromatic-mode (MFM)** (detection/dose performance optimization)
- **Short-and-monochromatic-mode (SM)** (pump-and-probe experiments e.g. when tens of fs long monochromatic pulses are needed

For the first experiments the source has been optimized for applications in medical imaging, mammography in particular (1st financed experiment at SL_Thomson: "MAMBO-BEATS").

Highest X-ray flux at about 20 keV, with a relative radiation energy spread < 20% and keeping as low as possible the high harmonics contribution.

From theory

- In the classical regime (electron energies E <10^{10} eV) the photon distribution can be written as:

$$\frac{d^2N_\gamma}{d\omega d\Omega} = \frac{\alpha}{4\pi^2}\omega\left|\vec{J}(\vec{n},\omega)\right|^2$$

with : $\vec{J}(\vec{n},\omega) = \vec{n}\,|\times\left(\vec{n}\times\int dt\vec{\beta}(t)e^{i\omega\left(t-\frac{\vec{n}\cdot\vec{r}(t)}{c}\right)}\right)$, r=electron position, β = electron speed.

In the case of a planar flat-top laser pulse * the spectral distribution can be written as:

$$\frac{d^2N_\gamma}{d\omega d\Omega} \cong \sum_{n=1}^{\infty} V(n,\vartheta,\varphi)\,\delta(\omega - n\omega_f)$$

where :

$\omega_F \cong \omega_L \cdot 4\gamma^2/\left(1+\gamma^2\tilde{\vartheta}^2 + {a_0}^2/2\right)$ and $\tilde{\vartheta}^2 = \vartheta^2 + {\vartheta_e}^2 - 2\vartheta\vartheta_e\cos(\phi - \phi_e)$

*-P. Tomassini et al Appl. Phys. B 80, 419-36 , 2005
-P. Tomassini et al. IEEE Trans. on Plasma Sci. 36,n.4, 2008

HFM2 WP

$$N_\gamma \propto \Psi^2 \frac{(1+\Psi^2+2\Psi^4/3)}{(1+\Psi^2)^2}$$

$$\Delta\omega_F/\omega_F \cong \Psi^2/(1+\Psi^2/2)$$

$$\Psi^2 \equiv \gamma\vartheta_M$$

for $\Psi^2 << 1$

$$N_\gamma \propto \Psi^2 \frac{(1+\Psi^2+2\Psi^4/3)}{(1+\Psi^2)^2}$$

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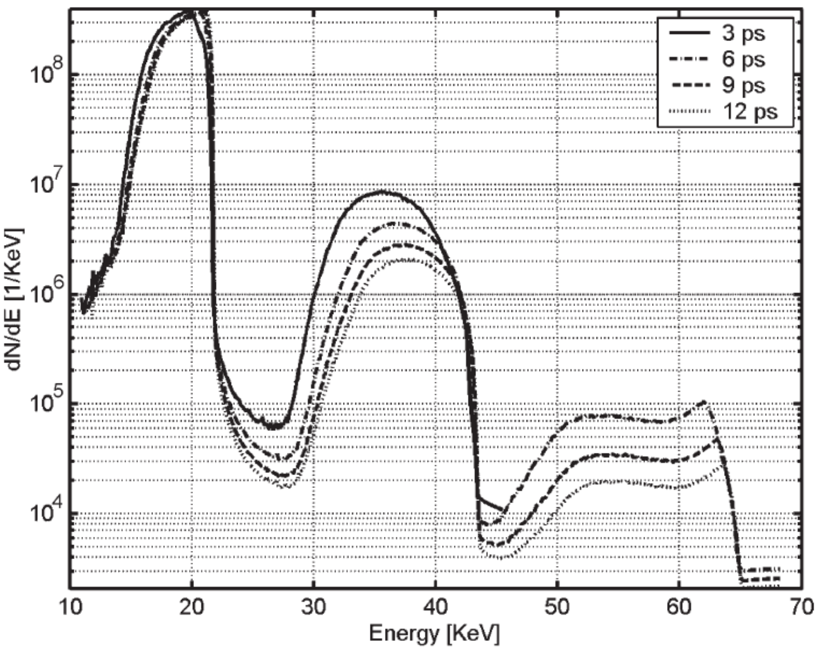
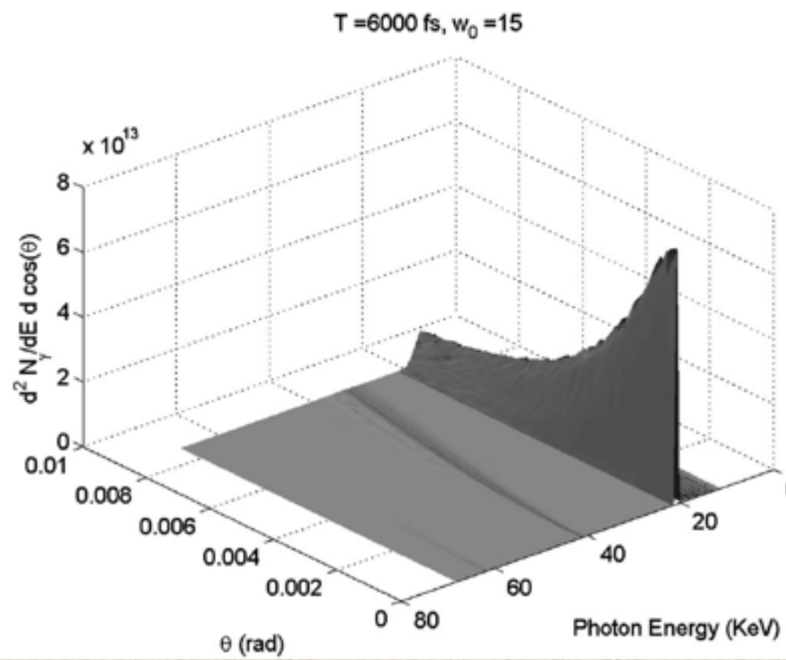


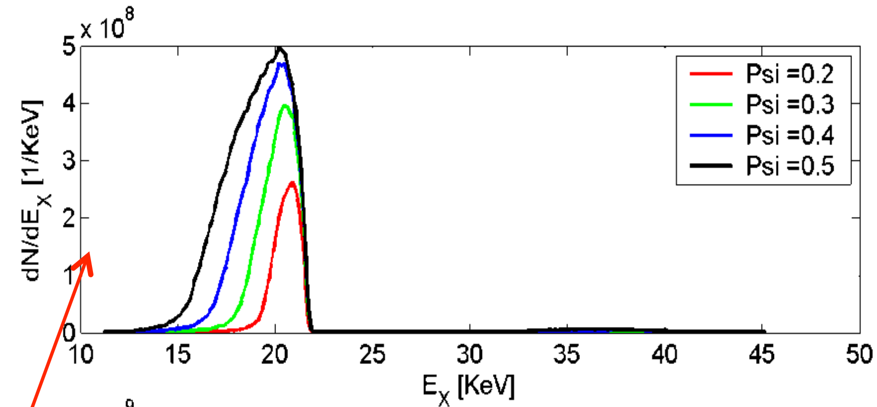
Spectra of the collected radiation for pulses of duration 3, 6, 9, and 12 ps.

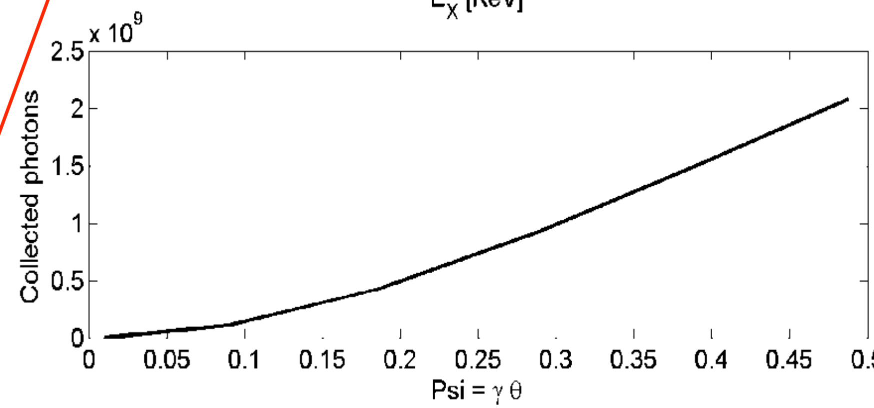


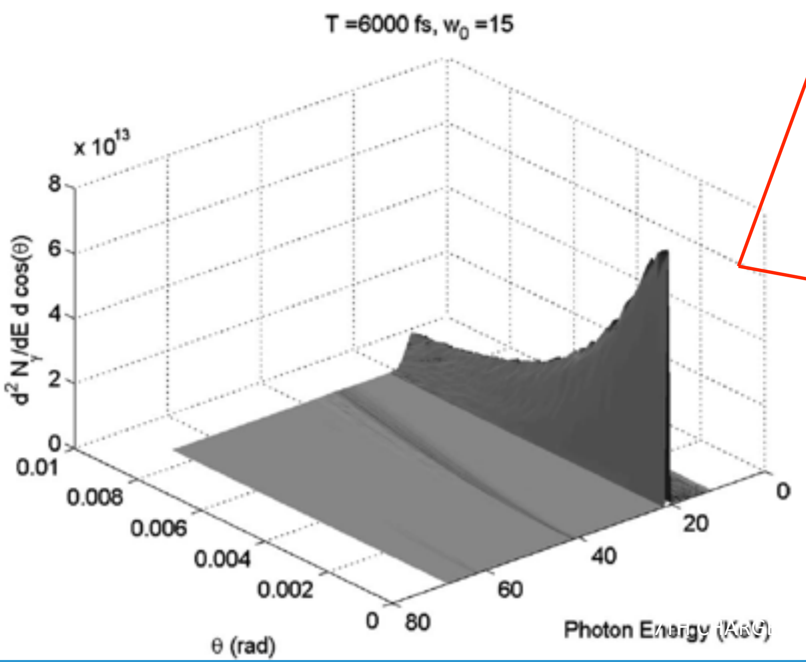
Spectral–angular (integrated in the azimuthal angle φ) distribution of the collected radiation for the optimized parameters w = 15 μm and duration T = 6 ps, where θ_M = 8 mrad

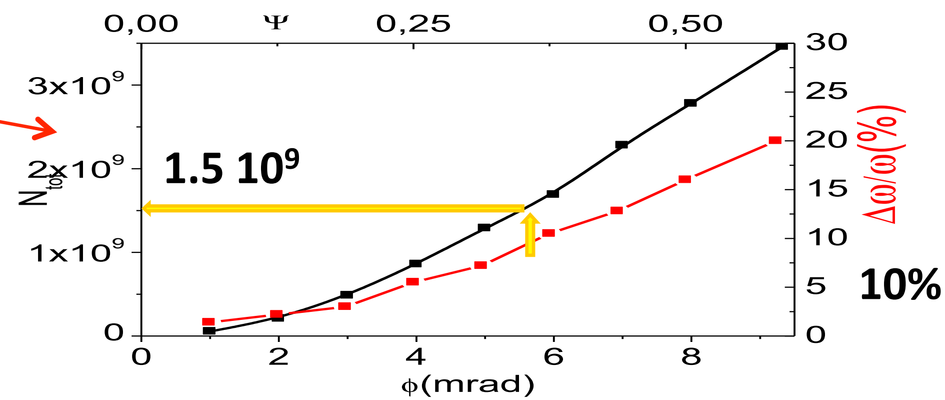
30 MeV WP:

- e-beam:
  - Charge Q =0.25-1×10^{-9} C
  - Energy E =30 MeV
  - $\sigma_{xy} \approx$ 15-20μm
- photons: **(V. Petrillo)**
  - energy= 22 keV
  - Dg/g= 7 10^{-4}, e=0.8-1.5mm-mrad
  - Interaction angle = 0°





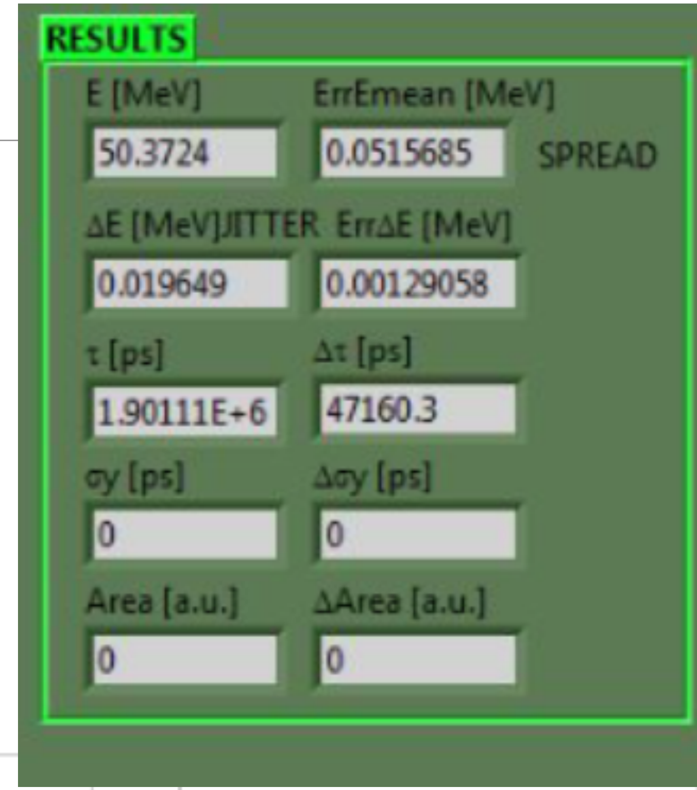


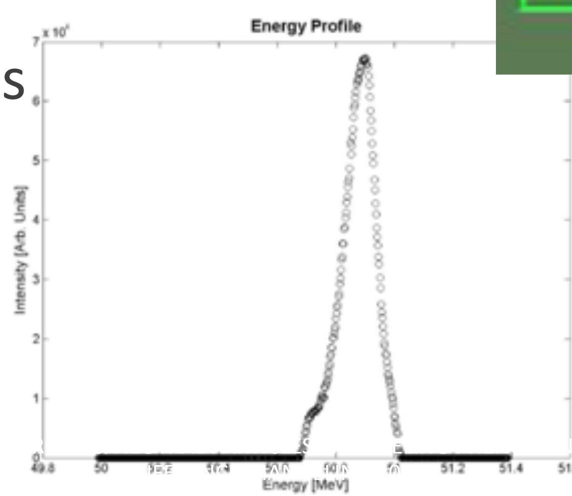


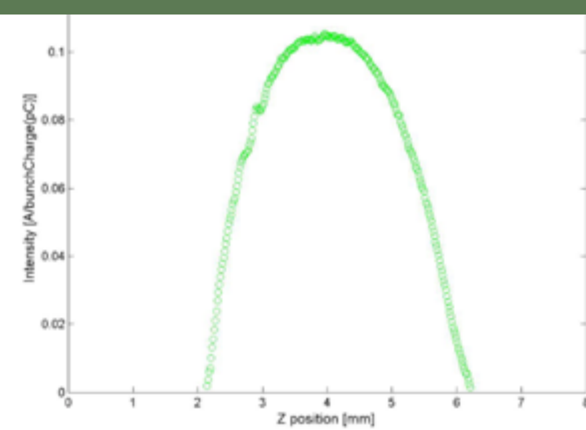
1st commissiong phase (Feb. 2014-1 month shift)

50 MeV Working point

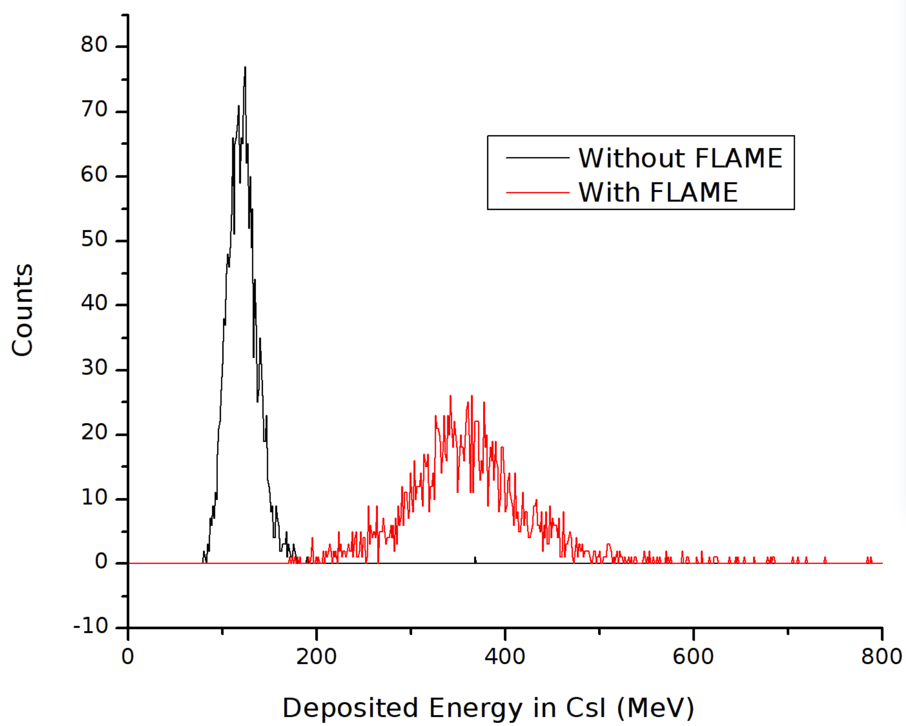
- Charge (daily avrg):Qav= 200 ± 20 pC
- Energy (daily avrg):Eav= 50.6 ± 0.2 MeV
  - Launch phase: Φ= + 30°
  - Laser pulse length = 8.3 ps
  - 1st TW S1 phase: Φ= - 20°
  - 2nd TW S2 phase: Φ= + 65°
  - 3rd TW S3 phase: Φ= - 90°
  - Bunch length rms = 3.1 ps



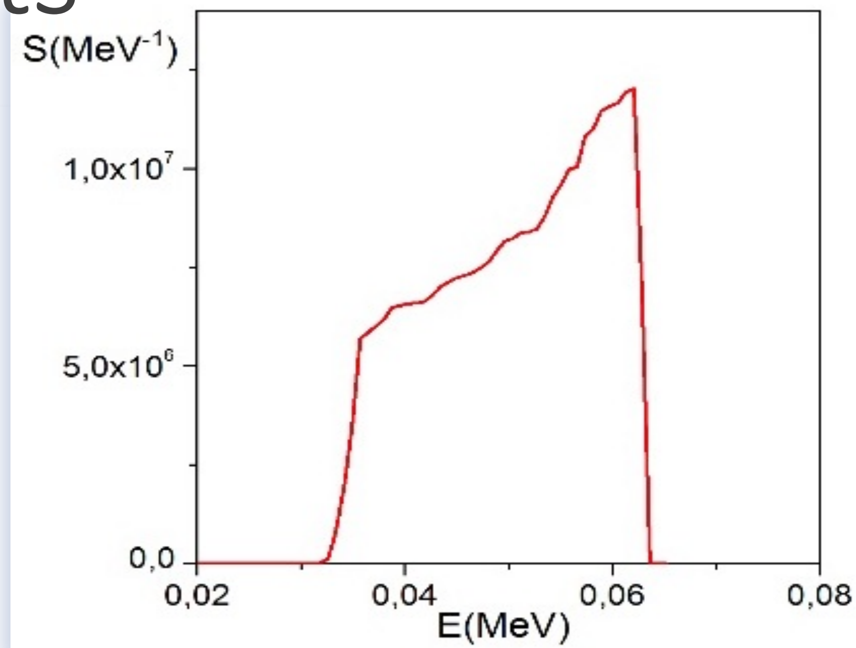




Experimental results



Thomson x-rays signal in red, in black the electron background signal (without FLAME laser), integrated over 120 s (1200 pulses) We calculate that the number of photons per each pulse, coming from poor overlap conditions, and interacting with the detector sensitive area, is in average 6.7×10^3.



Spectral density S (MeV^{-1}) versus photon energy. (50 MeV electron beam, with 200 pC charge, 5 mm mrad of emittance, 150 mm of rms beam transverse dimension, colliding with the laser with 500 mJ and 30 mm of waist, gives a number of photons of 2×10^5 in a bandwidth of about 19%.

The photon energy edge, given by $E_p \sim 4E_L g^2$, is about 63 keV.

The 2nd Commissioning phase June 2015 dedicated shift: 30 MeV e⁻beam

- With the available hw (phase shifters only on 3 TW's) the applied acceleration/deceleration scheme worked well enough to produce a low energy spread e^- beam at 30 MeV, even though resulting in a strong sensitivity for the e^- beam to the machine imperfections/ stability.
- So the background contribution to the X-ray detector prevented the elctron beam rms spotsize in collision to be lower than 110 μm (minimum reached 60 μm)
- The expected photon flux was:

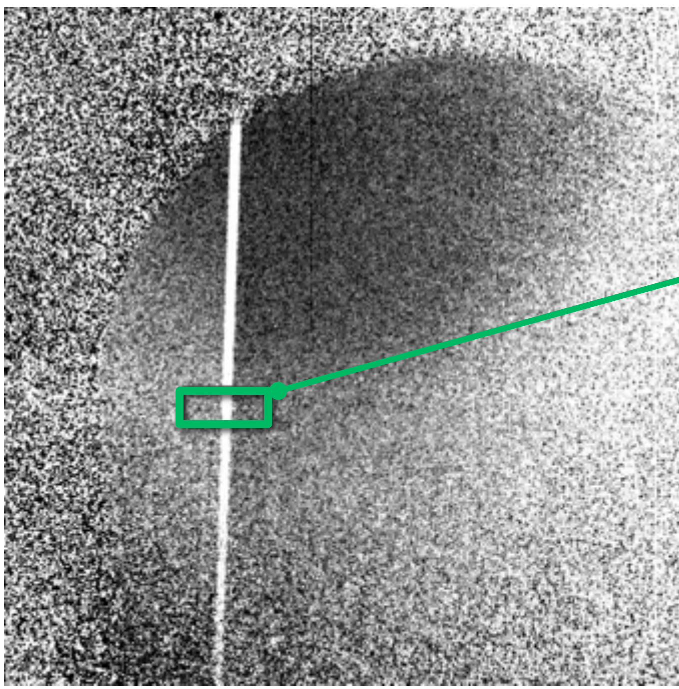
$$N_{\gamma}^{bw} = 5.8\cdot 10^{8} \frac{U_L [J] Q[pC]}{\sigma_x^2 [\mu m]} \gamma^2 \theta^2 \approx 1.4\cdot 10^{6}\ photons/sh$$

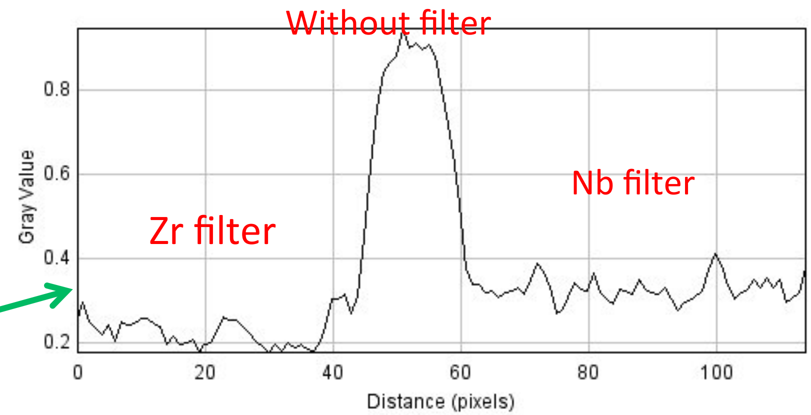
with:

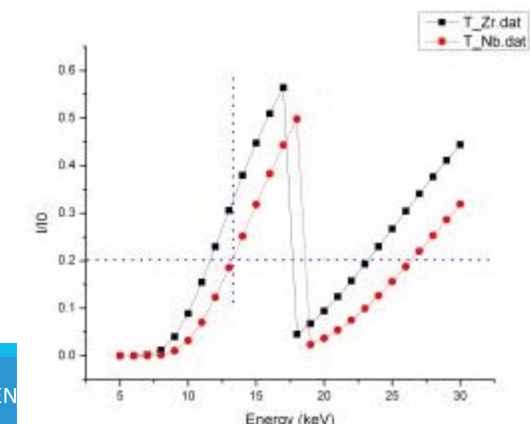
$U_L \approx 2$ J, Q≈ 200 pC, $\delta_{\Phi} = 0.2$, hv=1.55eV, $\sigma_{x,y} \approx 110\mu m$, $w_o \approx 150\mu m$

Radiation measurements

- **The charge measured** (depends on conditions, around 10 pC per pulse) **in a Si PIN diode** (Hamamatsu, 28mm x 28mm x 0.3mm), by an electrometer (Keithley) **previously calibrated** using monochromatic source (Elettra synchrotron) **is compatible with 10^4 photons (@ 20 keV) per pulse** on the detector sensitive volume
- The measurement of the absorption by different k-edge filters Zr and Nb (19 and 18 keV) allows to estimate the incident energy distribution, comparing the measured values with the theoretical ones. As shown in the plot below, **in the region highlighted in green, the energy is compatible with 13.5 keV**

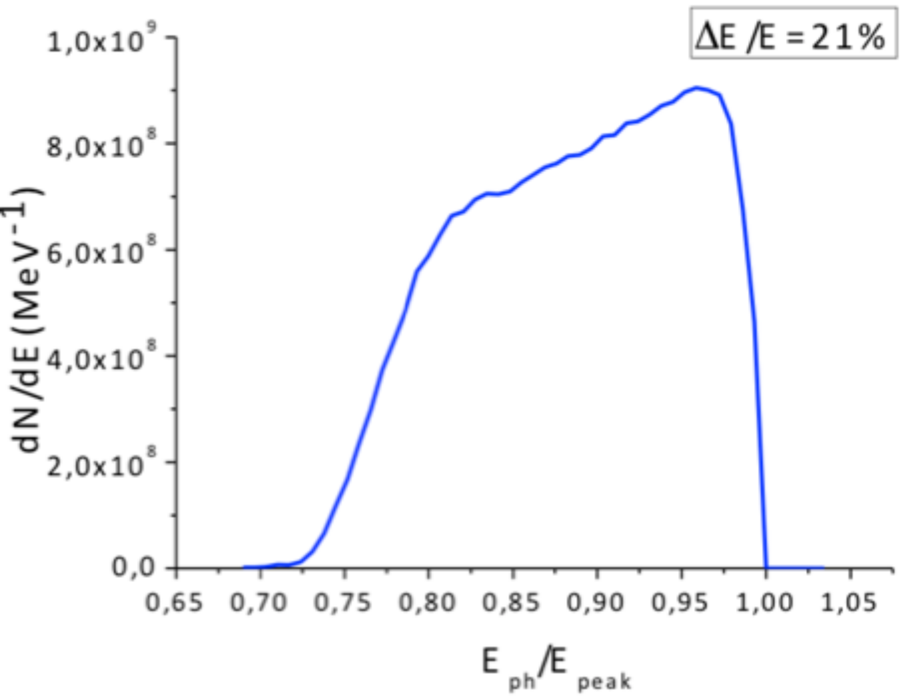


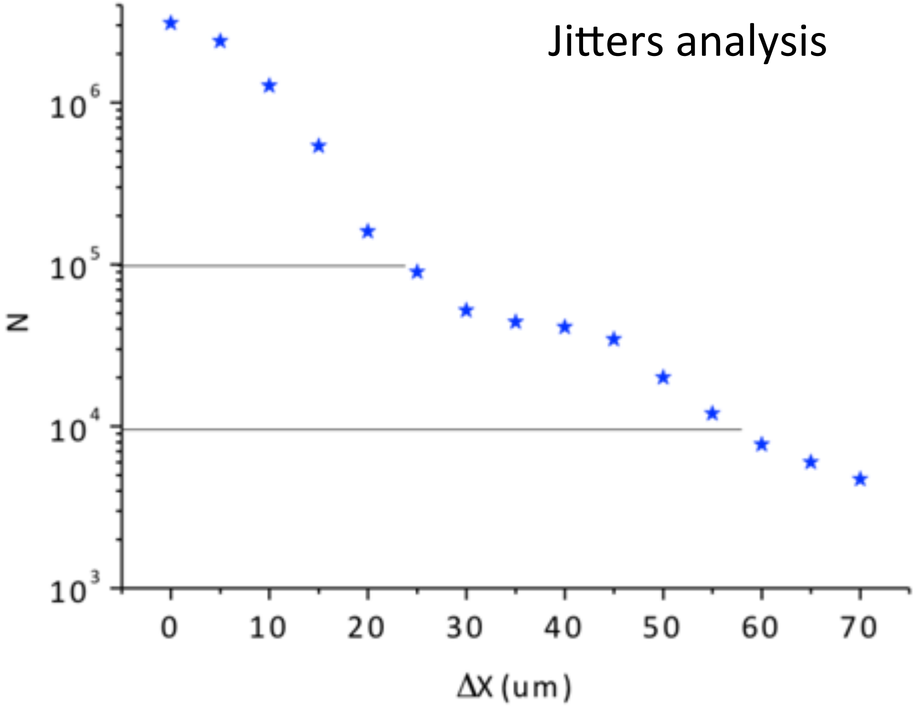




Spectral simulation with a real electron beam transported up to the IP

Spectrum of the photons at the IP
Acceptance angle: 9 mrad (parabolic mirror hole acceptance)





E_{peak}=22.5 KeV
DE/E (FWHM)=21%

Off axis trajectory effects w the solenoid field map

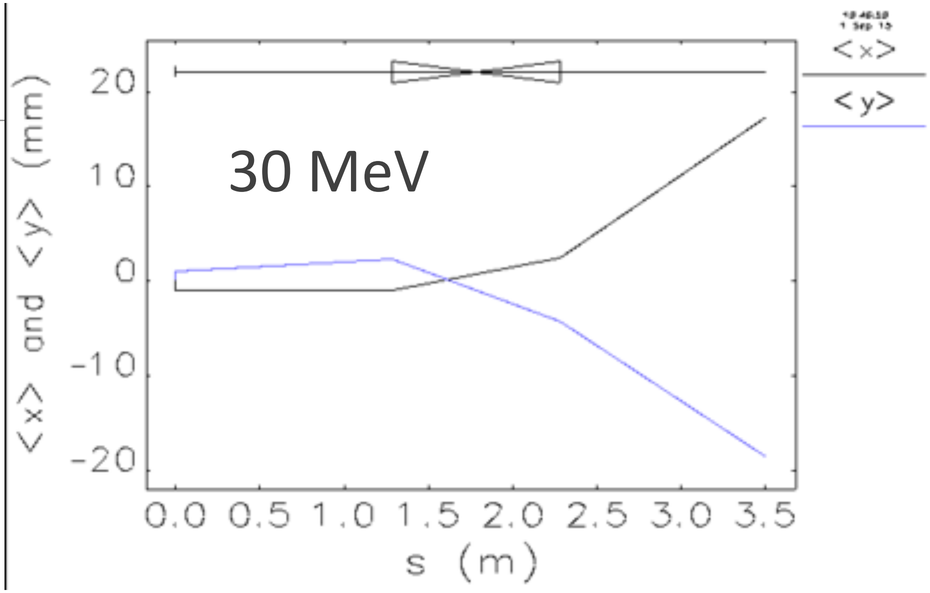
A 4-5 mm offset at the exit of the final window (about 3.5m) can mean a non negligible offset and angle at the entrance of the focusing solenoid, much more severe as long as lower is the electron beam energy.

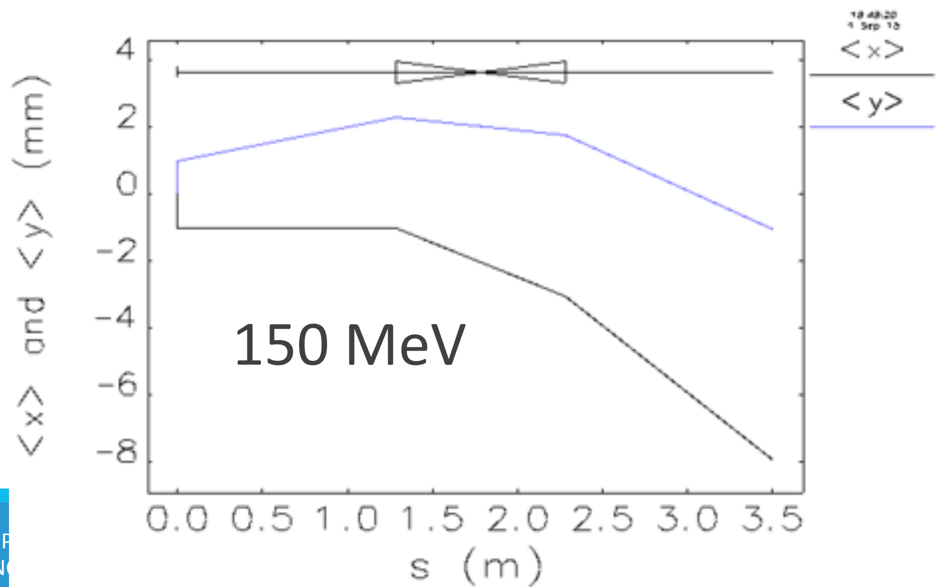
Qualitative example: Δx,y= 1 mm Δyp=1mrad

E= 30 MeV -150 MeV

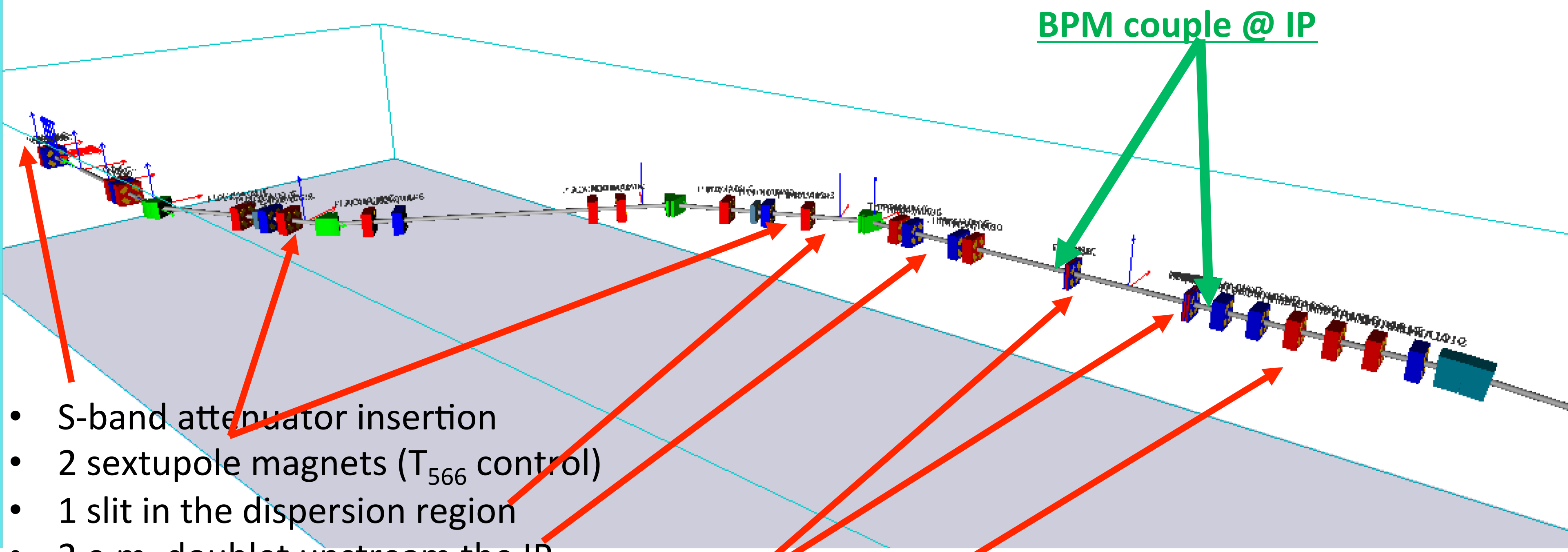
Perspex window Φ=35 mm

Figures: centroid trajectory up to the window



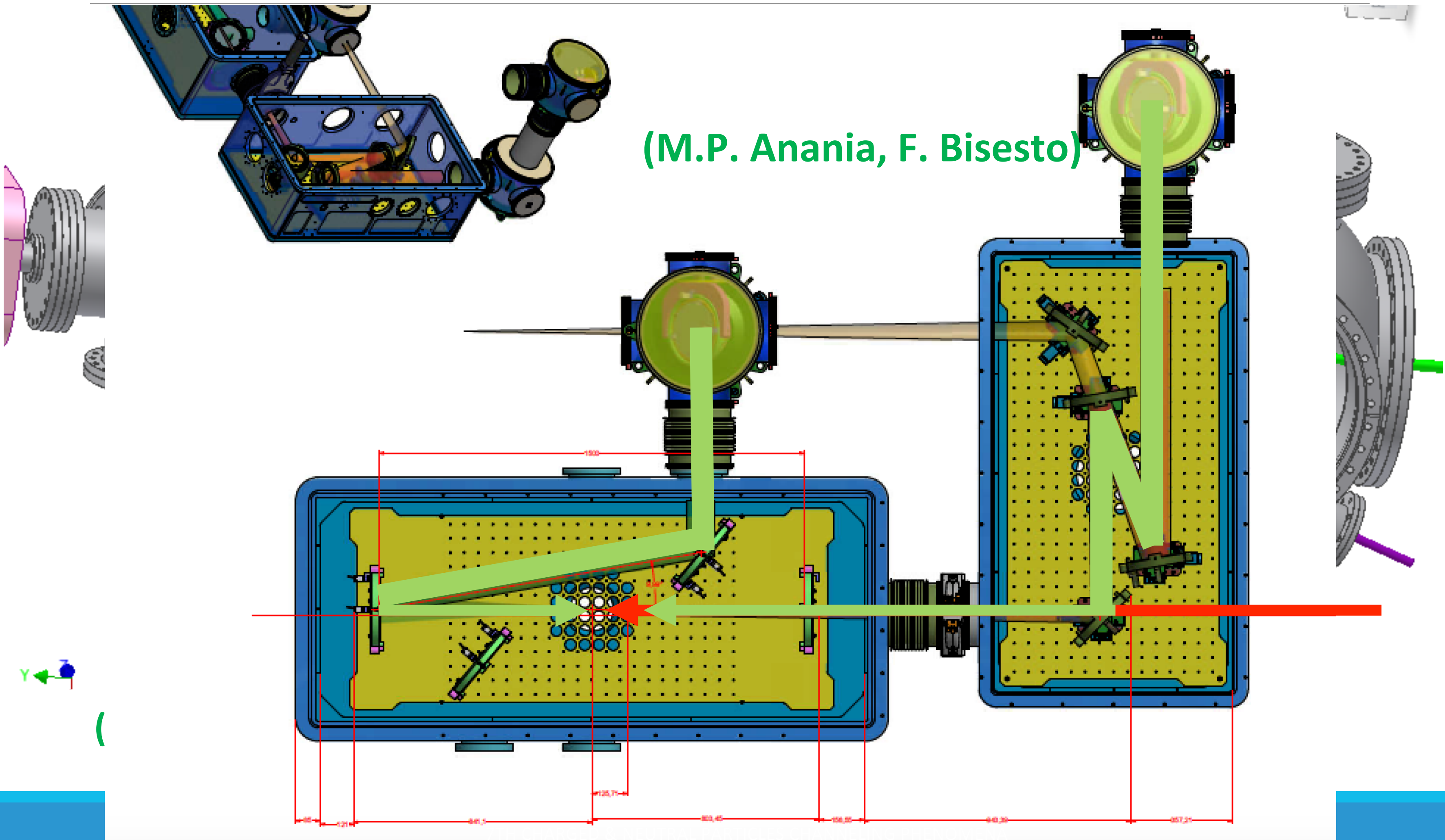


New layout: same beamline for LWPA & ICS experiment

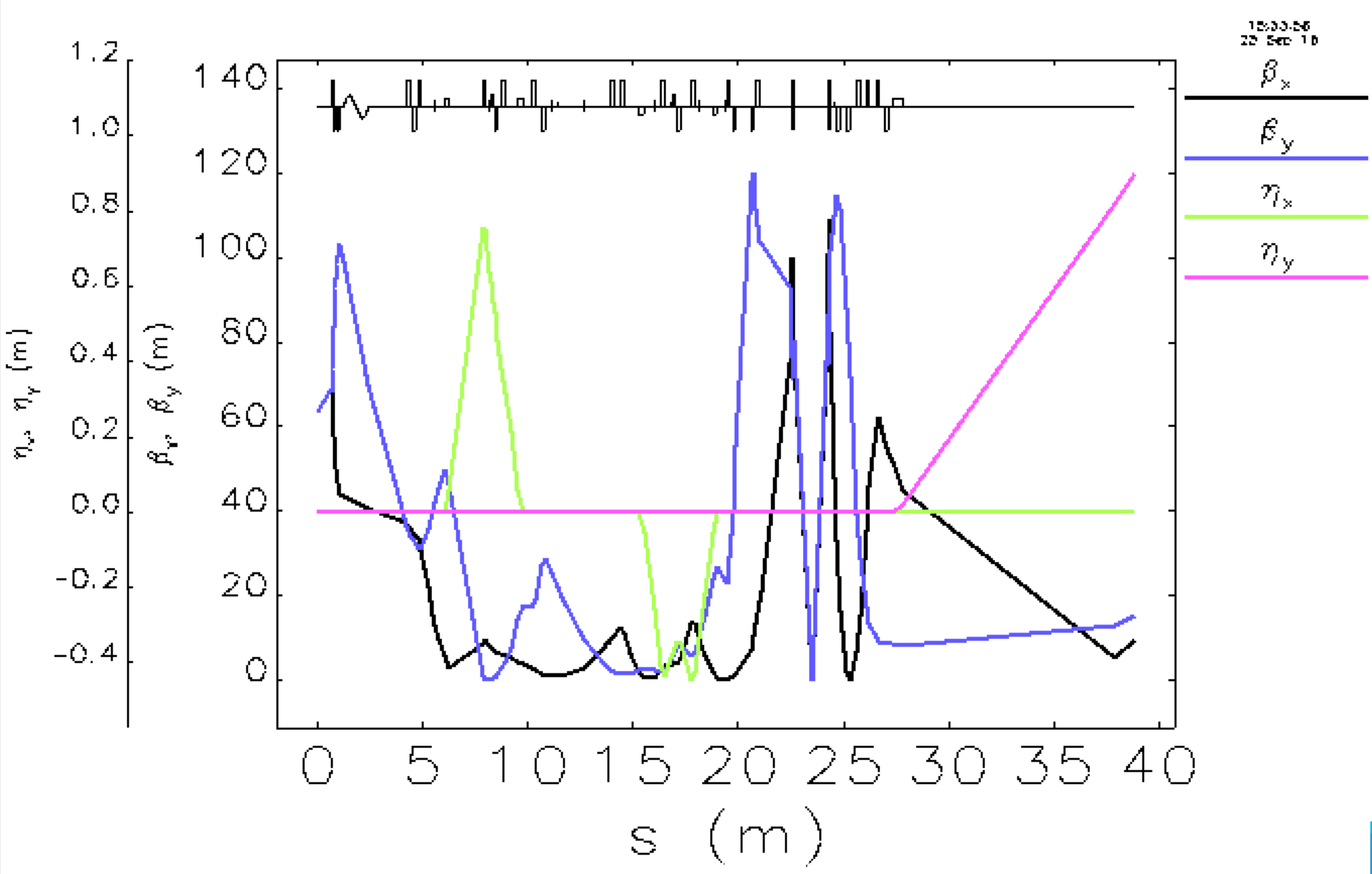


- S-band attenuator insertion
- 2 sextupole magnets (T_{566} control)
- 1 slit in the dispersion region
- 2 e.m. doublet upstream the IP
- IP focusing perm magnets (double set)
- High energy focusing system and bending for 6D beam characterization after interaction (LWFA acceleration & Compton scattering)

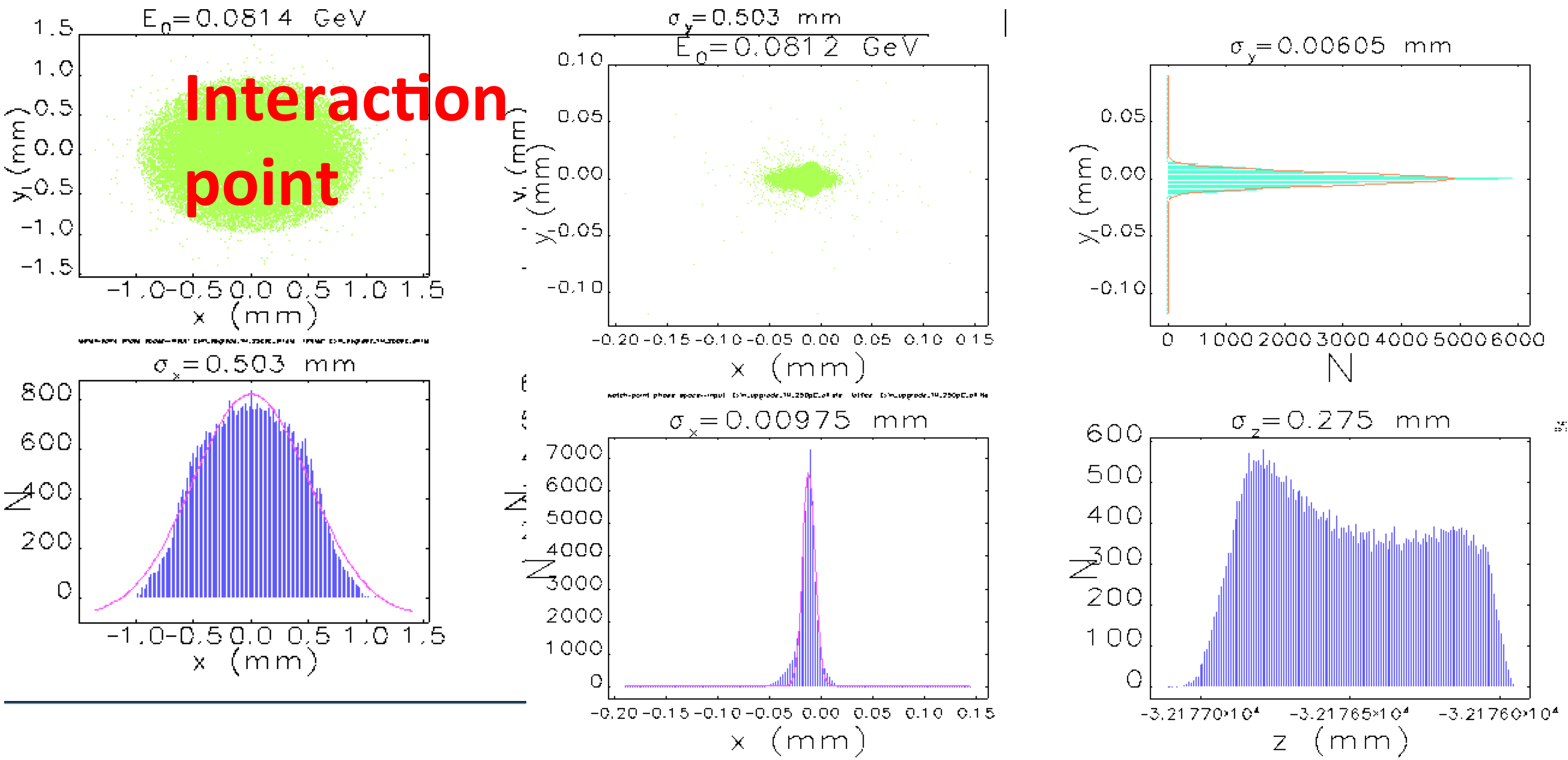
IP layout NEW



Twiss parameters for Thomson case (250 pC, 80 MeV)



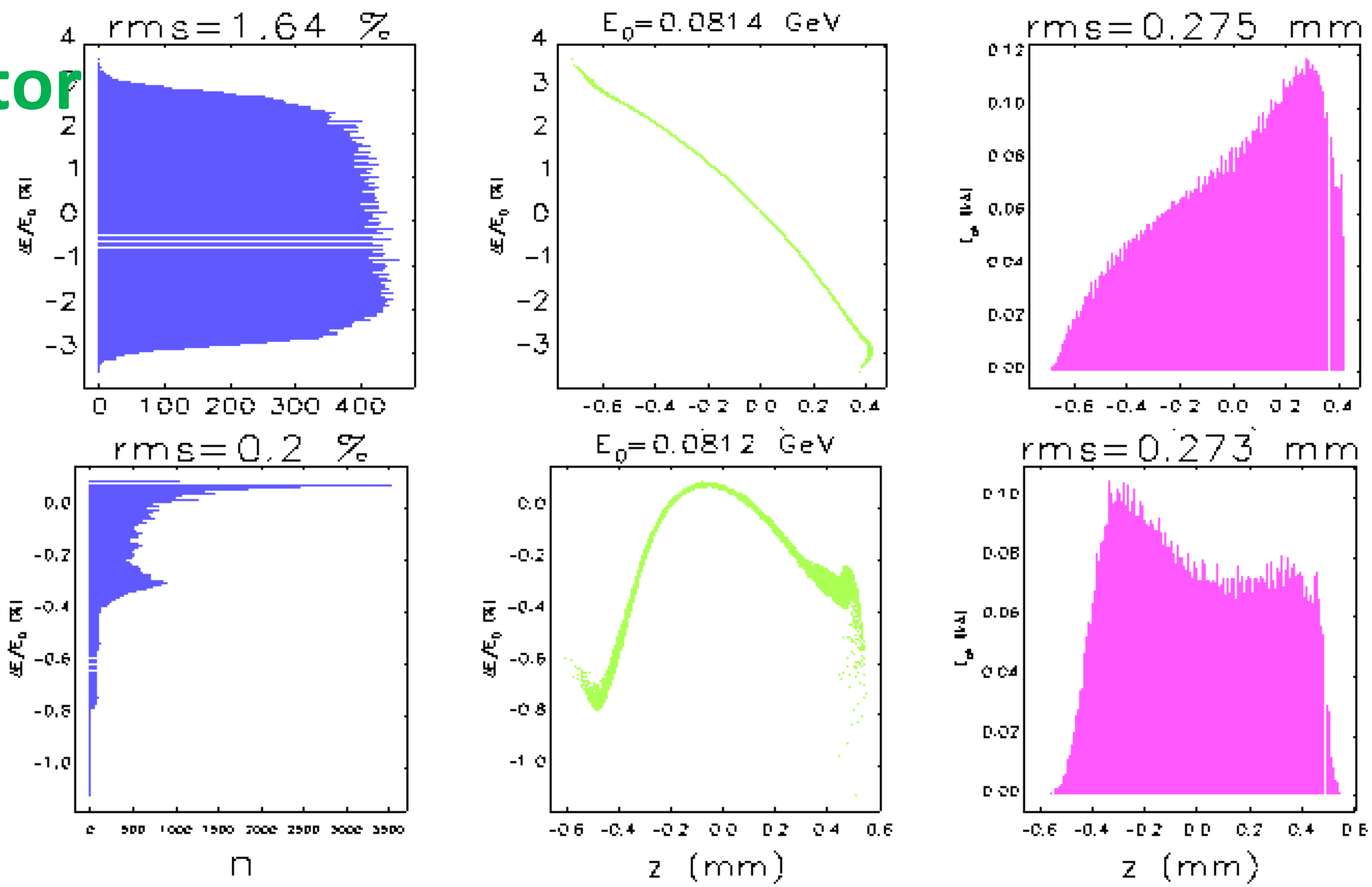
e⁻ beam transverse phase space for Thomson source



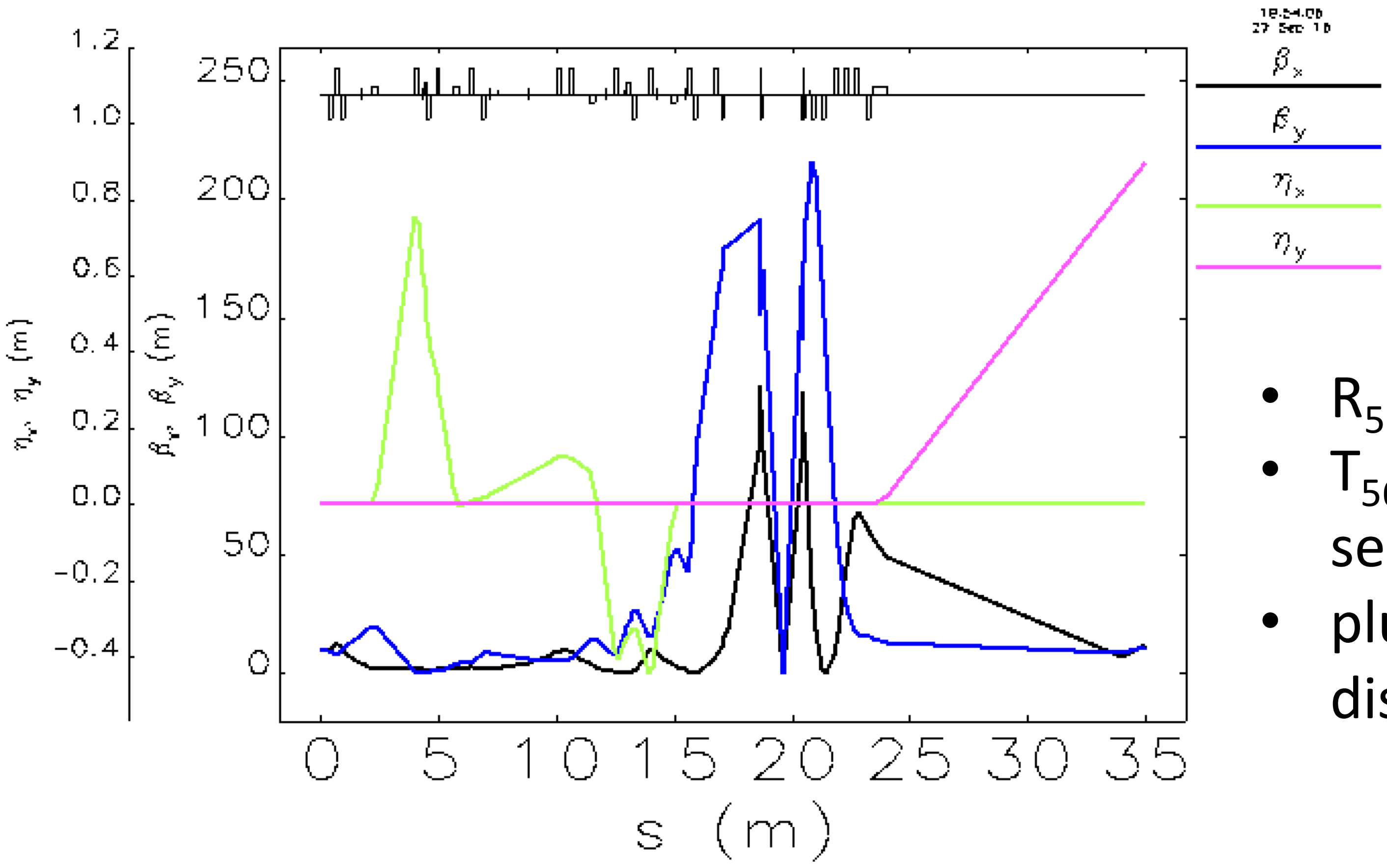
Longitudinal phase space for Thomson Case

Photoinjector exit

Interaction point

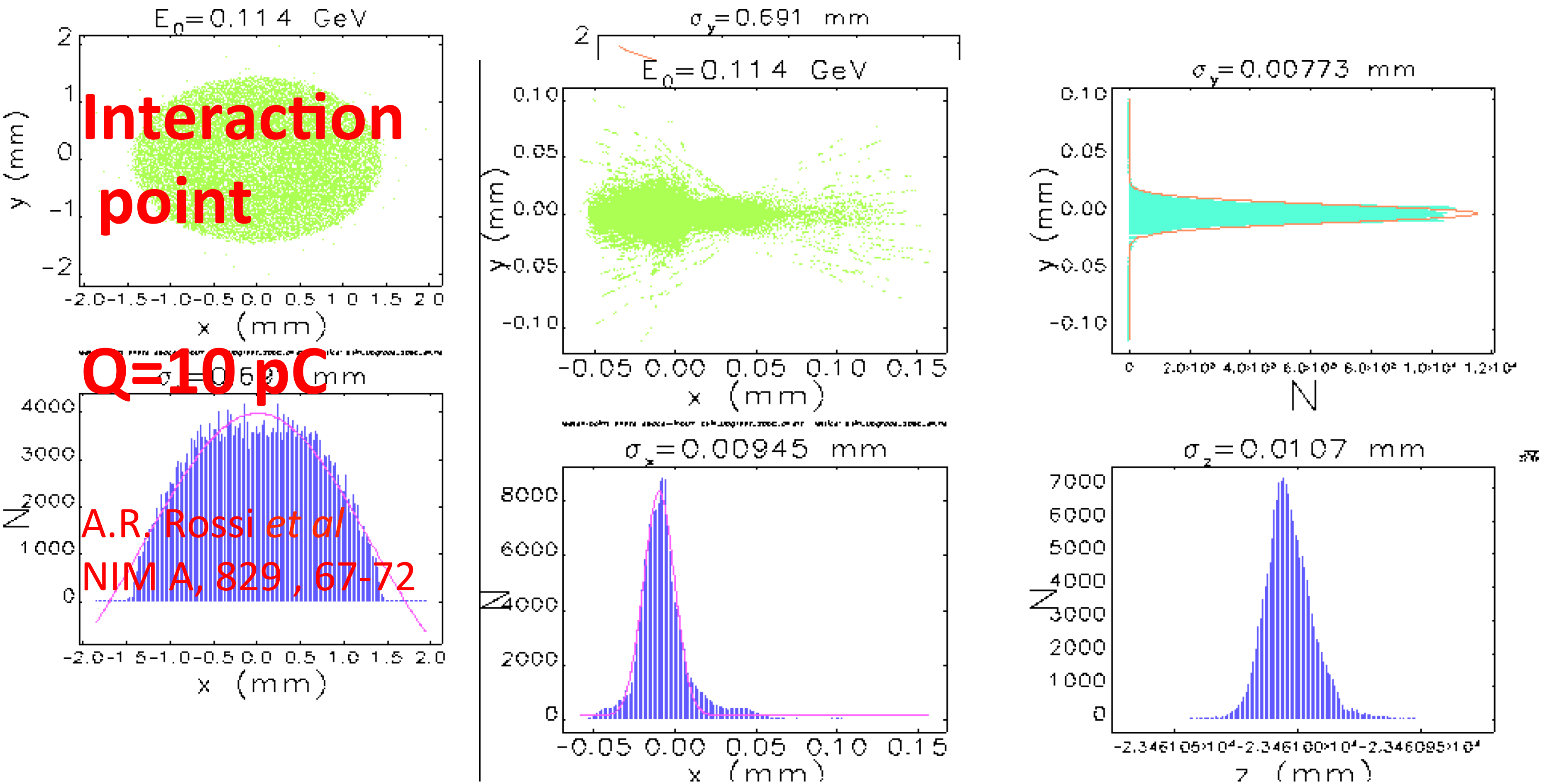


Twiss parameters for Exin case (20-50 pC, 80-160 MeV)



- R_{56}=5-6 mm
- T_{566}<1 mm w sextupoles
- plus slit in the 2nd dispersion region

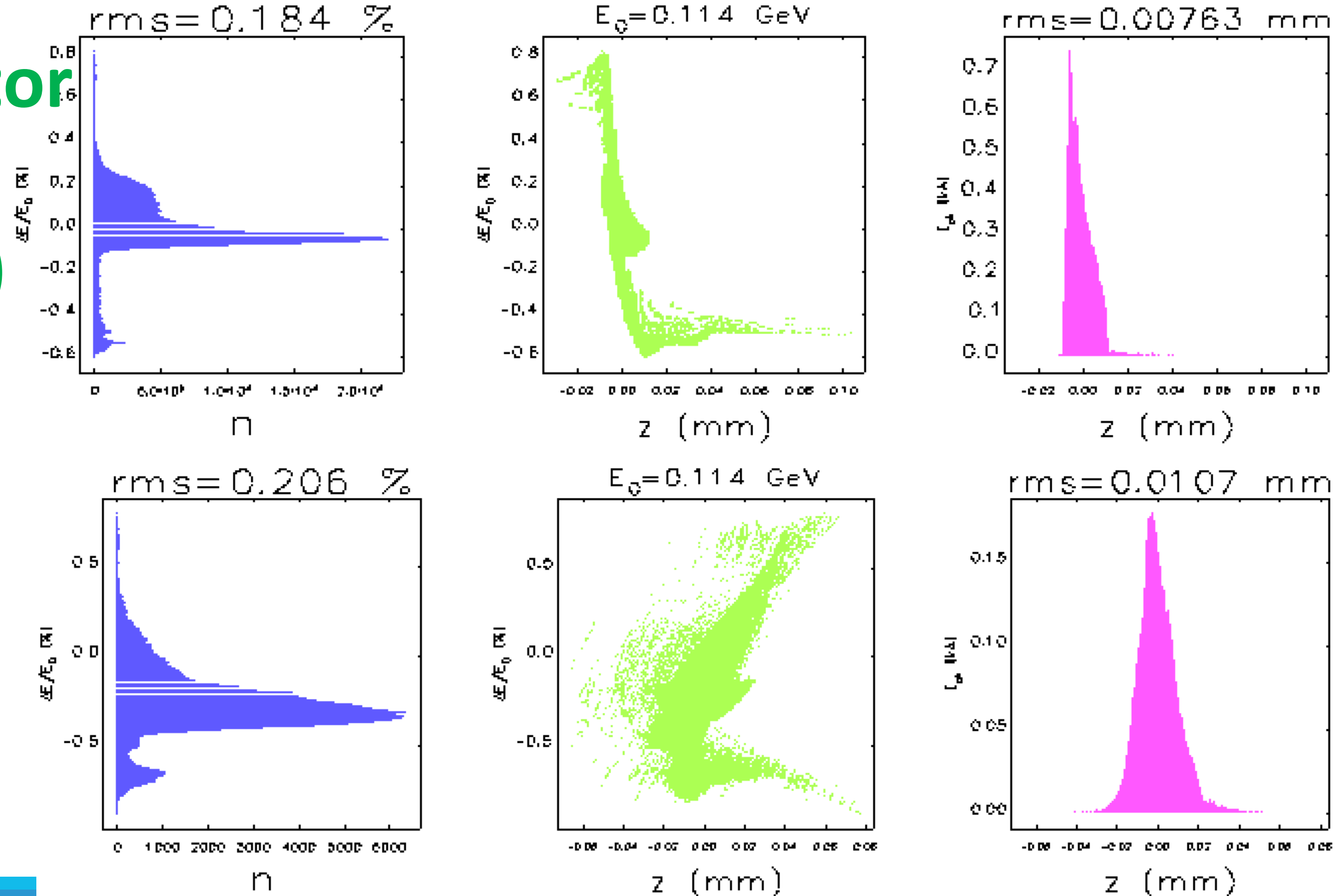
e⁻ beam transverse phase space for Exin experiment LWPA



Longitudinal phase space for Exin Case

Photoinjector exit (R. Pompili)

Interaction point



Conclusions

- Taking advantage from the past Thomson Source experience and coupling the effort on the Exin beamline experiment an upgraded beamline has been studied to perform electron beam interaction with counter and co-propagating laser beam coming from the FLAME system.
- All the needed extra magnets and power supplies are already present except the PMQ triplets
- The beam pipe from the second dogleg has to be provided with a beam dumper as well.
- Reasonably the procurement can be completed by January 2017